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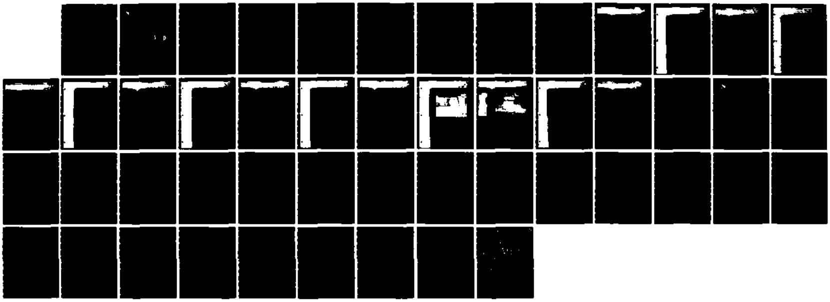

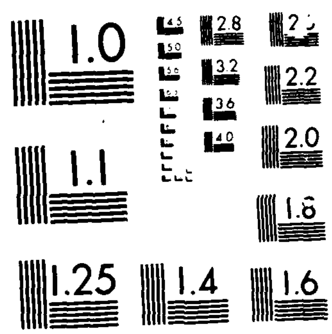

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REMOTE OPTICAL SETTLING TUBE

FINAL REPORT TO THE OFFICE OF NAVAL RESEARCH
FOR CONTRACT NUMBER

N00014-84-C-0045

by

Robert Bartz
OST Ref. 02-86
February, 1986

Approved:

Richard W. Spinrad
President

Date:

28 FEB 1986

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16. Abstract

A remote optical settling tube was designed, calibrated and tested at Sea Tech, Inc. The instrument was delivered to the Woods Hole Oceanographic Institution where it underwent preliminary field testing. Problems encountered in the field testing phase were addressed and solved at Sea Tech and the instrument was returned to Woods Hole for deployment. The remote optical settling tube was moored in the Atlantic Ocean as part of the ongoing HEBBLE research program. Recovery of the mooring will take place in April 1986. Software was developed and tested at Sea Tech for the analysis of data from the settling tube. This software has been used successfully on a previous data set obtained with a prototype optical settling tube.

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INTRODUCTION

A Remote Optical Settling Tube (ROST) was constructed and calibrated by Sea Tech, Inc. and delivered to the Woods Hole Oceanographic Institution (WHOI) in compliance with the tasks outlined under contract number N00014-84-C-0045 with the Office of Naval Research (ONR).

A prototype version of the ROST had been developed under previous contract with ONR and its application and performance have been outlined in both the final report to ONR for that contract (N00014-83-C-0734) and the published research involving preliminary field tests of the instrument (Bartz, et al., 1985; Appendix 1).

After delivery to WHOI the instrument underwent further refinements and testing and was finally deployed in a mooring during a research cruise of the High Energy Benthic Boundary Layer Experiment (HEBBLE). Software was developed at Sea Tech, Inc. (and tested using data sets from the prototype instrument) for the eventual analysis of the data from the ROST.

DESCRIPTION OF TASK COMPLETION

The design for the ROST has been outlined in a previous final report from Sea Tech, Inc. to the Office of Naval Research (Sea Tech, Inc. Reference OST Ref. 11-83) and in a publication by Bartz, et al. (1985; Appendix 1). The instrument fabricated under this contract (N00014-C-0045) is of the identical design as the prototype described

in these references. Tests and calibrations were conducted at Sea Tech, Inc. These measurements were made to assess the response of the ROST under a wide range of environmental conditions. Appendix 2 shows the results of these tests as well as the necessary information for the development of an accurate data acquisition system for the ROST as delivered to Woods Hole Oceanographic Institution. The data in Appendix 2 demonstrate the following characteristics of the ROST as tested in the laboratory:

- Stability of the ROST in clear water
- Adequacy of the seal of the closing lids on the ROST (i.e. no "optical crosstalk" between the inside and outside of the ROST)
- Response of the ROST to a turbid environment and the rapid flushing of the ROST after lids are opened

The ROST was delivered to Woods Hole Oceanograpic Institution on 14 June 1984. Initial tests of the instrument in sea water presented problems with the motor housing. Upon return of the motor housing to Sea Tech, Inc. the expansion bellows were redesigned. The new bellows and motor housing were returned to Woods Hole where the instrument was re-assembled in August 1984. Appendix 3 contains a complete description of the subsequent problems encountered by Dr. Albert Williams in attempting to control and acquire data from the ROST using the hardware and software associated with his BASS instrument package. Subsequent failure of the light emitting diode source in the transmissometer was corrected at Sea Tech, Inc. and the recalibrated and retested transmissometer was again returned to WHOI on 30 July

1985 (Appendix 4). This recalibration and retesting was performed as requested in the extension of the original contract (Modification No. A00001 to Contract N00014-84-C-0045 issued 15 July 1985).

The ROST underwent dockside testing at WHOI by Dr. Williams, however difficulties were encountered in interfacing the BASS recording and controlling system with the ROST. Consequently no data were acquired during these field tests. Cable leakage problems were detected during a test deployment of the ROST during the KNORR 116 research cruise. These problems were solved at sea and the ROST was finally deployed with the OMNI Tripod at the following location

Date of deployment	21 September 1985
Time	2026Local
Latitude	40 26.84N
Longitude	62 21.85W
Depth	@ 2500fm

Recovery of the ROST is scheduled for 14 April 1986.

The final task required of this contract was the reduction of data obtained from field deployment of the ROST. No data were received upon the expiration of this contract, however the software necessary for the eventual reduction of these data have been developed at Sea Tech,Inc. This software is designed to analyze and process the Memodyne data tapes from the ROST data acquisition system and output the following information in both graphic and tabular form:

- Time series of light transmission over a given time (e.g. one day experiment period) both inside and outside the ROST.

- Tables of computed event times, associated settled-particle diameters, change in beam attenuation coefficient, calculated numbers and standard variations in particle concentrations and the computed concentration-weighted settling velocity for a given particle population.

A data set was chosen for testing the software developed under this contract. A test deployment of the prototype ROST as developed under contract with ONR in 1983 provided two separate suites of data for analysis with this software. Each of these experiments lasted one day and the analysis of the data is shown in Appendix 5. The data analysis follows the method outlined by Bartz et al. (1985).

SUGGESTED FUTURE WORK

The degree of extensive research and development that has been put into the Remote Optical Settling Tube suggests that there is a potentially large number of applications for the instrument in the future. The ROST itself is now a viable tool for measuring particle size distributions *in situ*. Several upcoming research projects in such areas as the Peruvian upwelling region (NITROP program) and thermal vents studies in the North Pacific stand to benefit from the types of data obtainable with the ROST. The emphasis of future research with the ROST should be the development of a data acquisition/control system. Ongoing development of new, stable light

sources with unmatched accuracy at Sea Tech, Inc. may provide such a degree of resolution in the ROST. Matching resolution of 0.01% (e.g. using a 14 bit A/D converter) should be the goal of the future research and development of a data acquisition system associated with the ROST.

CONCLUSIONS

A Remote Optical Settling Tube (ROST) has been manufactured, tested, and calibrated by Sea Tech, Inc. as per the specifications of the original contract with the Office of Naval Research. The instrument has been delivered to Woods Hole Oceanographic Institution and is now deployed in the Atlantic Ocean until April 1986. The software has been developed for analysis of the optical data obtained from the ROST. This software has been satisfactorily tested with previously obtained data.

APPENDIX 1

Marine Geology, 66 (1985) 381—395
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ROST AND BEAST: DEVICES FOR IN-SITU MEASUREMENT OF PARTICLE SETTLING VELOCITY

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ABSTRACT

Bartz, R., Zaneveld, J.R.V., McCave, I.N., Hess, F.R. and Nowell, A.R.M., 1985. ROST and BEAST: Devices for in-situ measurement of particle settling velocity. In: A.R.M. Nowell and C.D. Hollister (Editors), Deep Ocean Sediment Transport — Preliminary Results of the High Energy Benthic Boundary Layer Experiment. Mar. Geol., 66: 381—395.

The principles and design of two devices are described that measure the particle settling velocity in situ. The Remote Optical Settling Tube (ROST) designed by a group at OSU has been successfully deployed at the HEBBLE site. The Benthic Autonomous Settling Tube (BEAST) has recently been operated at the same site.

INTRODUCTION

Estimates of the rate of transport and deposition of sediment and of its vertical distribution in the flow require as a parameter the still-water settling velocity of the suspended particles, w_s. For example, rate of deposition is given by:

$$R_n = C_n\, w_{sn}\, (1 - \tau_0/\tau_n)$$

and the advection-diffusion equation for the concentration of suspended sediment is:

$$\frac{\partial C_n}{\partial t} = \frac{\partial}{\partial z}(w - w_{sn})\, C_n + \overline{C_w' w'} + \frac{\partial}{\partial z}\left(K \frac{\partial C_n}{\partial z}\right) + S_n$$

Here C_n is the volume concentration of suspended sediment, w_{sn} the settling velocity of the nth component and τ_n the limiting shear stress for its deposition, K is the eddy diffusion coefficient, and S_n is the source or sink of particles caused by aggregation or disaggregation of suspended material (Hunt, 1954, 1969; Einstein and Krone, 1962; McCave and Swift, 1976; Smith, 1977). The familiar Rouse (1937) equation for steady-state distribution of suspended sediment with height above the bed has the gradient as $(w_{sn}/\kappa u_*)$ in a log-log plot, κ is the Von Karman's constant and u_* is the

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shear velocity $(\tau_0/\rho)^{1/2}$. Thus knowledge of w_s is essential to sediment transport modeling.

Where sand is the suspended material there are fairly good relationships between grain size and settling velocity. However, where the material is fine and cohesive the settling velocity depends on the aggregation of particles. This is not a constant or simple function of size, concentration, and flow speed, and no method for predicting it has been proposed. It must be measured, and because aggregates are often very fragile it should be measured in situ.

Previous work in this field has been entirely in estuaries and on samples fractionated for settling velocity on board ship. Swift and Pirie (1970) analyzed their samples by the photo-extinction method of shining a light through the settling suspension and noting the change in concentration as a function of time. This method was also employed by Allersma et al. (1967) in their study of the Chao Phya estuary in Thailand. A more rigorous treatment of this method is given by Zaneveld et al. (1982) and is the basis of one of the new devices described in this paper for in situ measurement in the sea.

The most successful device used in estuaries has been the Owen tube (Owen, 1971, 1976). This tube samples horizontally in flowing water, and on being raised to the surface swivels into a vertical position to start settling of material. The tube is then used as a conventional bottom-withdrawal tube, samples being removed from the bottom in timed sequence and their suspended sediment content determined gravimetrically. Several estuaries have been examined by the Hydraulics Research Station (1977, 1979) using this device (data summarized in McCave, 1984). It is demonstrated that settling velocity increases with concentration over the range 50—1000 g m^{-3}. The rise of w_s with C is steeper for neap tides than springs (Owen, 1971), suggesting that the higher turbulent shear at springs limits growth of flocs relative to that at neaps. No comparable data exist from the continental shelf or the deep sea. The second device described in this paper was designed to provide settling-velocity data for use in sediment transport models in the High Energy Benthic Boundary Layer Experiment (HEBBLE).

DESIGN OF THE REMOTE OPTICAL SETTLING TUBE (ROST)

The theory behind the operation of the ROST has been set forth in Zaneveld et al. (1982). They showed that if one measures the beam-attenuation coefficient (c), as a function of time in a closed tube, filled with a homogeneous hydrosol, it is possible to derive a settling velocity distribution (SVD). If the specific gravity of the material in suspension is known, the particle-size distribution and the concentration weighted settling velocity for the sample can also be calculated.

The prototype ROST was designed to function in water depths of 5000 m for a period of several days to obtain particle settling velocity data. The settling tube was designed to provide a 25 cm column height, the path length for the transmissometer was 25 cm, and the tube was 10 cm wide. The transmissometer is described by Bartz et al. (1978). The transmis-

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someter was modified only to the extent necessary to mount it on the settling tube.

The opening and closing mechanism of the settling tube consists of a low-current drain stepping motor which slowly opens the top and bottom lids against a spring. When the lids are fully open the tube is allowed to flush for a period of 2 h; at the end of this period a clutch releases and the lids snap closed (within 2 s in water). The suspended material in the tube is then allowed to settle out for 22 h after which the procedure is repeated.

The OST was mounted on a tripod constructed by Mr. F. Hess at WHOI. The instrument height above the base was 0.75 m (measured from the base to the top lid).

DEPLOYMENT AND PERFORMANCE

The prototype ROST was deployed on the HEBBLE cruise of 1983 on 13 June, 1983, at 0137Z and recovery was on 15 June, 1983, at 0723Z. Preliminary data from this deployment were analyzed on board.

Primary concerns in the evaluation are:

(1) Does the settling tube flush adequately, so that the sample obtained is representative of the water outside of the tube?

(2) Does the closing mechanism properly isolate the interior of the tube from the exterior so that all "crosstalk" is avoided?

As a primary evaluation tool we used a second beam transmissometer mounted on the outside of the ROST. In this manner it was possible to determine equilibration time as well as monitor the outside environment while the interior particles were settling out.

Figure 1 shows the interior and exterior beam-attenuation coefficient (c) while the instrument is being lowered to the ocean bottom. During the downcast the closing mechanism is left open. Calibration of both transmissometers was accomplished by setting c equal to 0.37 when the instrument measured the cleanest water during the downcast (5.9—6.0 h). It can be seen that the exterior and ROST beam-attenuation coefficients agree to within $0.01/M$ during the rest of the cast ($0.01/M$ corresponds to approximately 10 μg per liter particle concentration).

Figure 2 shows data from one-half hour before the tripod touches bottom to two hours after it has landed. During the entire period shown the ROST lids are open. During the first half-hour of this figure the ROST is falling through the water column. Clearly visible is a bottom nepheloid layer with an intensity of $0.35/M$. It should also be noted that the interior and exterior transmissometers track perfectly through the nepheloid layer. A cloud of sediment is thrown up as the instrument tripod touches bottom. This cloud clears first in the exterior transmissometer and approximately 10 min later in the interior. For the remainder of the two hours the two transmissometers track very closely. It is thus shown that the equilibration time of the settling tube is approximately 10 min, although this should vary depending on

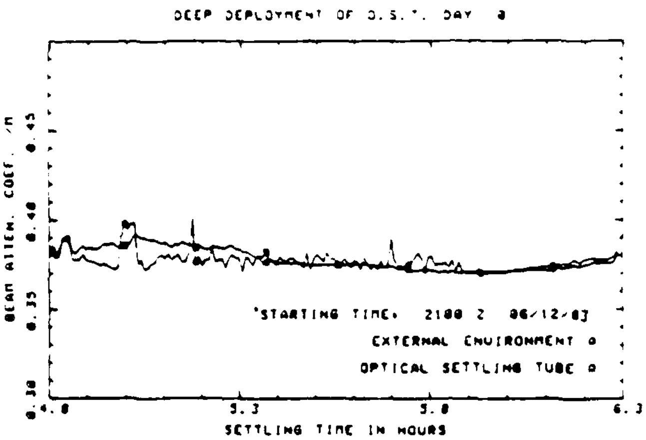


Fig.1. Beam-attenuation coefficient during lowering of ROST to sea floor.

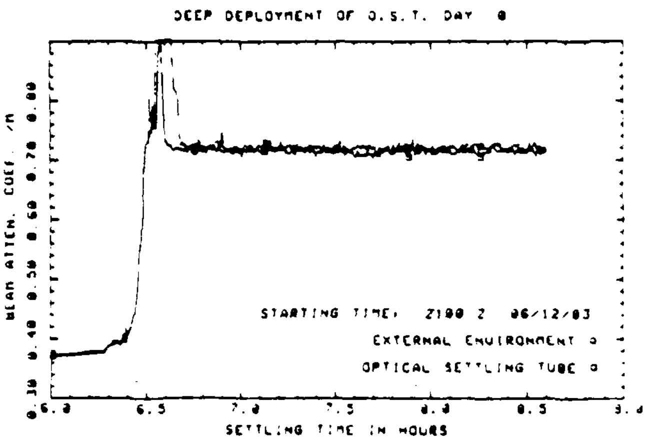
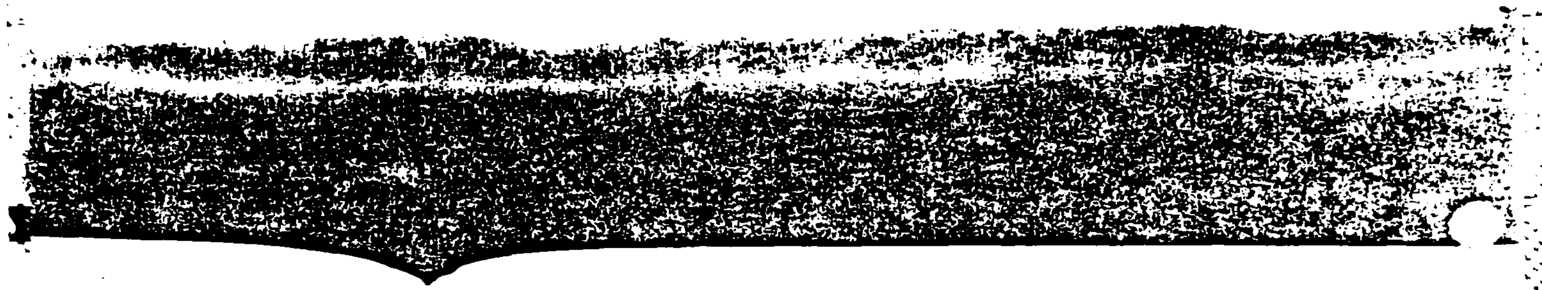


Fig.2. Beam-attenuation coefficient at landing showing clearing of cloud of suspended material.

current velocity. The current velocity for this time period was measured by Dr. A. Williams on a different tripod. Dr. Williams estimated that the current velocity in the location of the ROST tripod was between 3 and 8 cm s^{-1} during the two-day period that the ROST was moored.

The prototype ROST is designed to operate on a 24 h cycle, 2 h of which the tube is left open to equilibrate, after which the tube is closed and the transmission is monitored for 22 h, after which the cycle is repeated.

Figure 3 shows the first operational cycle of the ROST, and several features are of interest. The exterior beam attenuation shows high-frequency variations with an amplitude of about $0.02/M$ (approximately 20 $\mu g\ l^{-1}$). The interior beam attenuation shows no such high-frequency



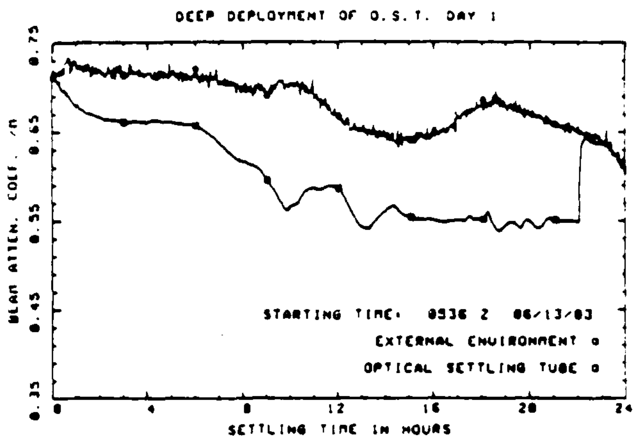


Fig.3. First deployment of ROST showing comparison of external environment with time history of settling within settling tube.

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fluctuations, showing that high-frequency turbulence outside the tube does not penetrate inside.

The beam attenuation inside the ROST generally declines as a function of time. In theory the beam attenuation should decrease continuously once the tube is closed, if the initial sample is well-mixed and if there are no outside influences. It is seen that after a steady decrease for the first 9 h there are several fluctuations on the order of $0.02/M$ from 9 h onward. How these fluctuations are generated is not understood at present and it is something that should be studied in the future. Possible causes are inhomogeneities in the original sample and disturbances of the fiberglass tripod. The fluctuations are probably not due to external changes in beam attenuation since fluctuations inside are often out of phase with outside fluctuations such as from 9 to 11 h.

The last 2 h show the beam attenuation as the tube is opened. Again the interior and exterior beam attenuation converge rapidly which shows good flushing characteristics of the tube and excellent tracking between the two transmissometers.

Figure 4 is an enlargement of the 2-h tube open period. It can be seen that the flushing time of the tube is approximately 20 min for nearly perfect tracking between the inside and outside transmissometers.

Figure 5 shows the second complete sampling sequence of the ROST. The same general features are apparent. The beam attenuation generally decreases, the exterior turbulence is much greater than the interior, and the interior signal shows low-frequency fluctuations with an amplitude of less than $0.02/M$. Notice again that the rapid decrease in exterior beam attenuation at 10 h does not coincide with a similar decrease in the interior. During the second day the initial beam attenuation was lower, and the subsequent decrease was less. Upon opening of the tube the interior and exterior equilibrated rapidly again.

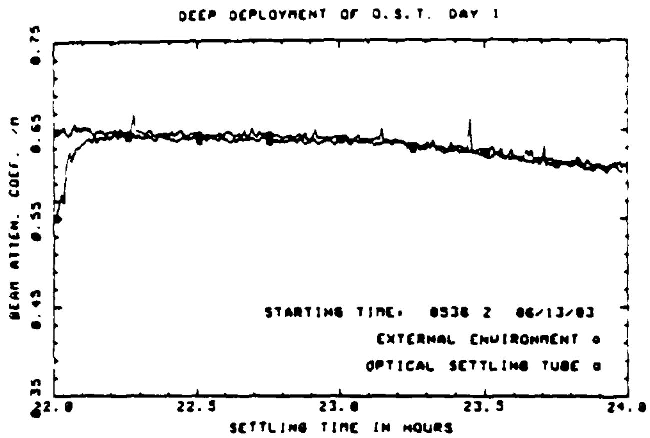


Fig.4. At end of first deployment, ROST is opened and two attenuation coefficients rapidly converge showing approximately 20 min flushing time for tube.

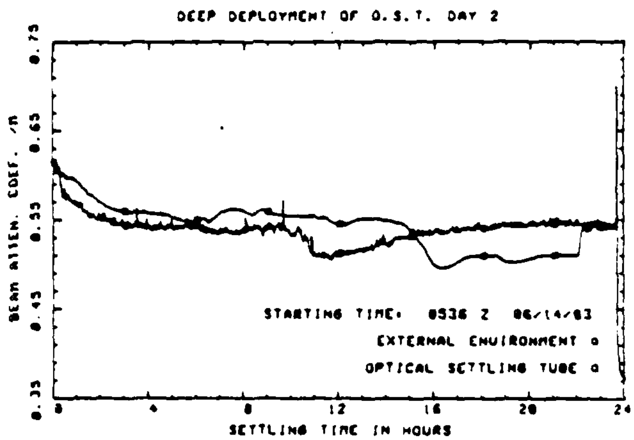


Fig.5. Second deployment of ROST.

Figure 6 shows the sequence from opening of the tube through release of the tripod at 23.6 h. Figure 7 shows the release and the subsequent upcast. It is seen that the interior and exterior beam attenuations agree very well. Comparing the downcast (Fig.1) with the upcast (Fig.7) it is seen that the instrument is stable within $0.01/M$ or about 10 $\mu g\ l^{-1}$ from launch to recovery.

Figures 8 and 9 show the natural logarithm, ln, of settling time versus percent transmission, t, for the two settling sequences. Because of Stokes law, ln t is proportional to ln d so that the lower scale is proportional to the ln of diameter d. Whenever the slope of transmission versus ln t is large,

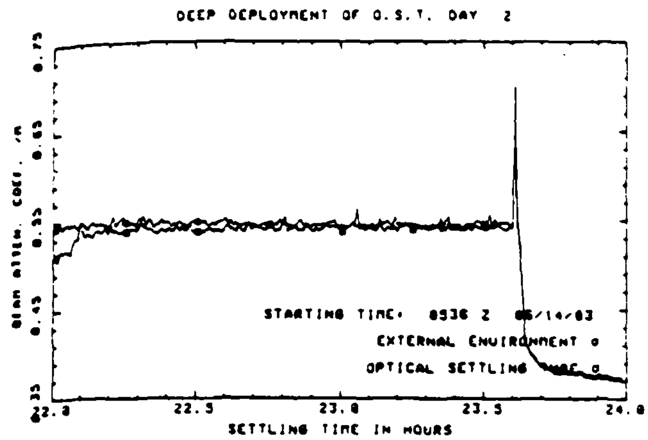


Fig.6. Operation of ROST from opening of tube until its release at 23.6 h.

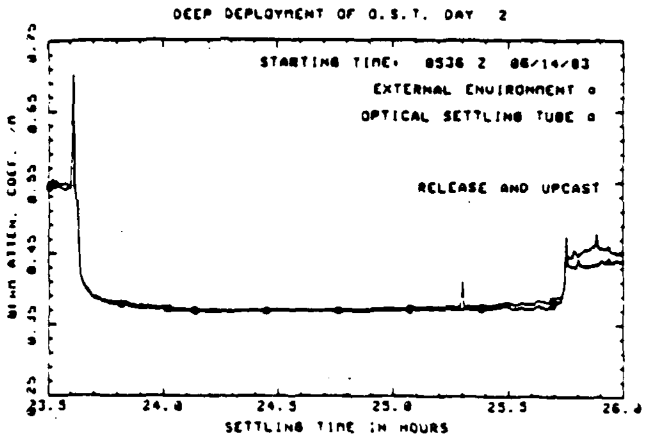
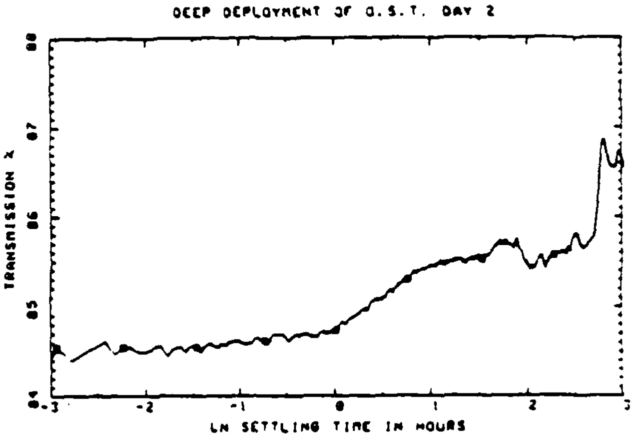


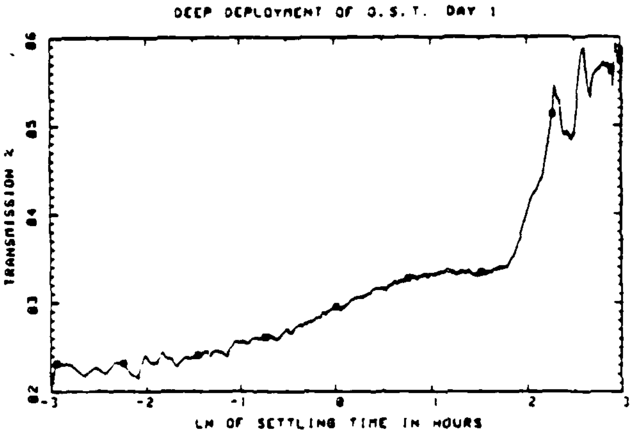
Fig.7. Release and upcast of ROST.

a maximum in the settling velocity distribution is encountered. Each day shows two such maxima, but they occur at later times, or smaller sizes on the second day.

CONCLUSIONS

The ROST worked as designed. No obvious crosstalk exists between the interior and exterior environment which shows that the closing mechanism worked properly during this experiment. Flushing characteristics are very good; flushing time was about 10 min in this environment. System accuracy and stability are excellent (about 10 $\mu g\ l^{-1}$). Beam attenuations generally decrease and clearly show peaks in the settling velocity distribution. Unresolved is the cause of the low-amplitude low-frequency fluctuations in the interior of the ROST.





Figs.8 and 9. Natural log of settling time plotted against transmission for the two operations of ROST (shown in Figs.3 and 5).

Subsequent work on the ROST will concentrate on calibration, reduction of data, and study of the low-frequency fluctuations.

PRINCIPLES OF THE BENTHIC AUTONOMOUS SETTLING TUBE (BEAST)

Sedimentation of a polydisperse suspension

The sedimentation of a homogeneous polydisperse suspension was formulated by Oden (1915). He reasoned that in such a system, after time t, the material settled to the bottom of a chamber of height h comprised two fractions: (1) a portion of the sediment with settling velocity $w_s(t) < (h/t)$; and (2) all of the sediment with $w_s > h/t$. The continuous settling velocity distribution function $m(w_s)$ is defined as $dm = m(w_s)dw_s$ where dm is the mass of particles per unit volume of suspension having settling velocity

between w_s and $w_s + dw_s$. For $w_s < w_s(t)$ the fraction of dm that has settled is $m(w_s)\,dw_s \cdot (w_s t/h)$. For the whole suspension the mass sedimented at time t is:

$$P(t) = \int_0^{w_s(t)} m(w_s)\,dw_s \cdot (w_s t/h) + \int_{w_s(t)}^{\infty} m(w_s)\,dw_s \qquad (1)$$

Differentiating yields:

$$\frac{dP(t)}{dt} = \int_0^{w_s(t)} m(w_s)\,(w_s/h)\,dw_s \qquad (2)$$

Thus the partially sedimented fraction, the first term on the right of eqn. (1), is $t\{[dP(t)]/dt\}$. If a curve is drawn of the cumulative mass sedimented $P(t)$ as a function of time t (Fig.10), it will be seen that the intercept on the ordinate of the tangent to the curve y' gives the portion which has completely settled out of suspension. Expressing y' as $f(t)$ [or $f(w_s)$ for given h] then gives the cumulative settling velocity curve, and a second differentiation yields the frequency curve.

The Bottom Withdrawal (BW) tube

The tube is a laboratory instrument designed to generate the sedimentation curve of Fig.10, and Owen's (1971) tube was its field equivalent for estuaries. The method, detailed by Vanoni (1975) and Owen (1976), involves taking the lowest 10 cm of an initially 1 m long column of sedimen-

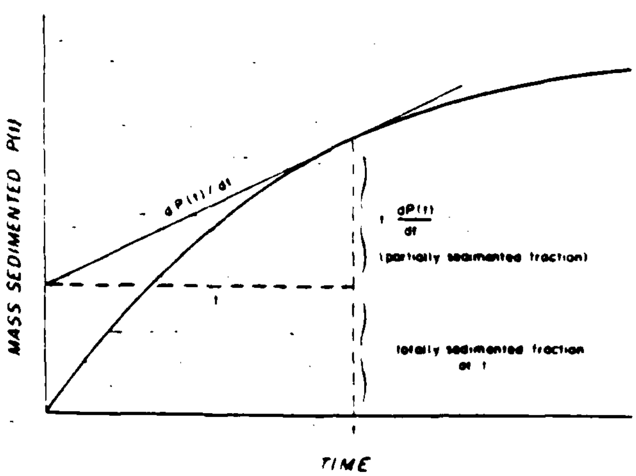


Fig.10. Cumulative sedimentation curve showing its differentiation to yield the totally sedimented fraction as one of intercept.

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TUBE (BEAST)

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ting suspension at successive logarithmically spaced time intervals. The withdrawn samples are then filtered or taken to dryness to determine the sediment content. The weights are corrected for the fact that successive samples come from a progressively smaller volume of the whole suspension, and the times are corrected for the fact that the later the sample the shorter the distance settled. The corrected cumulative weights are then plotted against corrected time as in Fig.10.

The Benthic Autonomous Settling Tube

The in-situ tube, whose acronym is BEAST, is designed to sink to the sea bed, collect a sample of water, allow its sediment to settle, and return to the surface. While the sediment is settling the tube performs a series of operations which are geometrically equivalent to the withdrawal of samples from the bottom of the BW tube. A series of partitions are slid across the tube in timed sequence from the bottom upwards. Thus rather than moving the water column down the tube, the bottom of the tube is moved up the water column. This operation is performed in the constant temperature environment of the sea floor, after which time the apparatus sheds ballast and returns to the surface. Here each of the 8 5-l compartments is filtered through 0.4 μm Nuclepore® filters for determination of the cumulative sedimentation curve. The weights so obtained are treated in the standard manner described by Vanoni and Owen and illustrated later in this note.

DESIGN OF BEAST

The BEAST was designed with several criteria in mind:

(1) Use materials for fabrication which undergo an absolute minimum of corrosion or abrasion attack in the marine environment. Obviously, a few grains of corrosion products could seriously upset particulate measurements where a few tens of micrograms may constitute the whole filtered sample.

(2) Provide adequate power to enable the use of tight seals in the sample compartments. Tight seals in the sample chambers are a clear necessity if contamination of samples from low particle concentration depths during passage through "dirtier" waters is to be avoided.

(3) The settling column proper must be as nearly smooth as possible to prevent particles from landing on exposed horizontal (or nearly so) surfaces.

The first criterion was met by using as little metal as possible (corrosion) and, where it was unavoidable, by using titanium (either C.P. grade or Ti6A14V alloy). The corrosion rates for titanium and its alloys, where it is not galvanically coupled, is so close to zero in cold seawater as to be totally insignificant. Titanium was used for all fasteners as well as for the actuating cylinders and, more critically, the sliding shutters.

The column itself is fabricated from a stack of Noryl® blocks. A 25.4 cm hole was bored through each 30.5 × 30.5 × 10.2 cm block. When stacked,

spaced time intervals. The
to dryness to determine the
or the fact that successive
ue of the whole suspension,
later the sample the shorter
weights are then plotted

is designed to sink to the
iment to settle, and return
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nt to the withdrawal of
ries of partitions are slid
om upwards. Thus rather
ie bottom of the tube is
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l® blocks. A 25.4 cm
lock. When stacked,

the eight blocks form an 81.6 cm high column (Figs.11 and 12). Noryl® was chosen for its dimensional stability, low water absorption, and ease of machining.

The frame and tripod descent vehicle were all fabricated from fiberglass. Commercially available tubing, sheet and angle stock were used as well as hand laid-up forms at various structural junctures.

The cost of the titanium components and the limitations on structure imposed by the use of fiberglass were felt to be justified both to meet the initial criterion and, possibly as important since the entire system spends much of its life exposed to the marine atmosphere either in storage or on the deck of a ship, to minimize necessary maintenance. No paint, preservatives, or routine care are required.

The second requirement, adequate power, was met in a unique way. The high hydrostatic pressures encountered in the deep ocean are put to work powering a set of hydraulic cylinders which actuate the shutters. Having over 3000 kg force available (at 5 km depth using 2.54 cm diameter cylinders) enables one to use high sealing pressures knowing that enough force is available to overcome the sliding friction of the shutter seals.

"Power" for the actuation cylinders is provided by simply sending an empty (i.e., 1 atm air pressure) cylinder down with the system. This acts as a hydraulic sump. The actuation cylinders, exposed to ambient pressure on one side and filled with ethylene glycol fluid, are vented into the sump through electrically operated valves. Essentially, full ambient pressure is available until the sump cylinder is over 95% filled. As the system rises back to the surface, a check valve bleeds off the high-pressure air to prevent an explosive opening of the sump at the surface. Resetting for the next

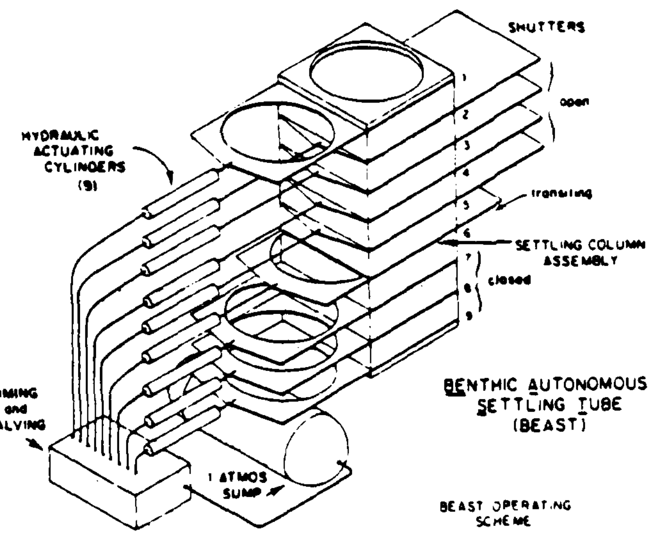

Fig.11. Block diagram of the BEAST.

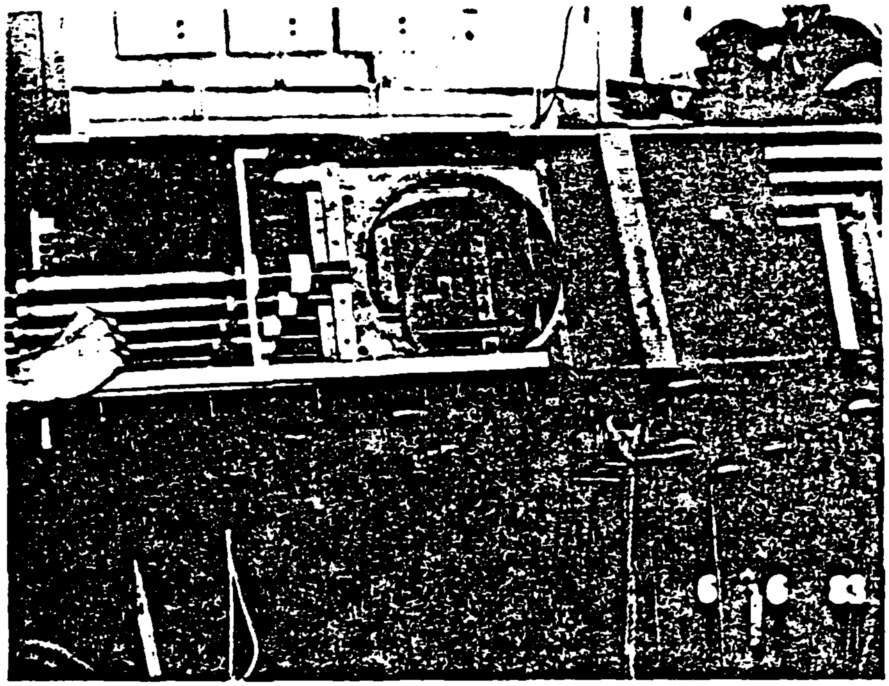

Fig.12. View of BEAST from above showing pistons (left), shutters, and (right) sedimentation column with the top shutter in closed position.

dive may be accomplished by manually pushing the shutters to their cocked positions or pressurizing the sump with air to force the glycol fluid back into the cylinders and drive them back to their open positions.

Smoothness of the settling tube bore is maintained by careful alignment of the (8) blocks and the shutter openings as well as the close fit of the shutters into their slots. Less than 0.25 mm opening exists in the tube wall at the shutters. All surfaces are machined to better than 10 μm RMS to minimize particle adhesion.

Control of the shutter timing is provided by a modified scheduling calculator (Sharp EL-6100). Initiation of the shutter sequencing may be by elapsed time or external command (e.g., bottom proximity sensor or switch). The EL-6200, batteries, and multiplex circuitry are enclosed in a small (15.2 cm diameter by 40 cm long) pressure resistant housing. A short electrical cable connects to the hydraulics control box. This box is of fiberglass and is oil-filled and diaphragm-equalized to ambient pressure. It contains demultiplexing and four-phase motor drive circuitry as well as the high-pressure valves driven by step motor. Step-by-step motors were chosen as there are no moving contacts in them. All electronics operate at ambient pressure in oil. Provision is made for electrically reversing the valves from the EL-6200 to prepare for the next deployment.

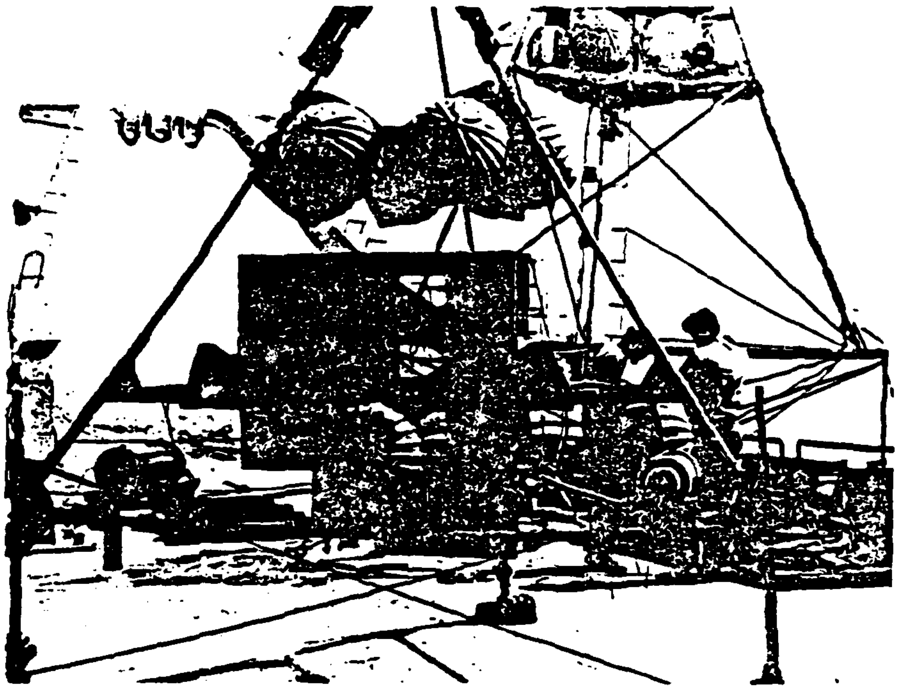

Fig.13. BEAST in its tripod showing electronics control pressure case (right), hydraulic control box (bottom of instrument), and hydraulic foot-release system (left).

The whole system is mounted on a fiberglass equilateral tripod approximately 3 m on each edge (Fig.13). The BEAST is mounted centrally with provision for canting for sample removal.

The tripod is fitted with flotation spheres as well as the usual beacon, strobe lights, and radio transmitter to facilitate recovery. An acoustic transponder with a command channel is also fitted. The transponder provides both location data while on the bottom, and provides a means of "calling" the instrument and causing it to shed its ballast "feet" so that it will float back to the surface. About 140 kg of droppable ballast is used, giving approximately 70 kg negative (descent) or positive (ascent) buoyancy. Descent and ascent speed is 45 m min^{-1}.

SHIPBOARD OPERATIONS

The instrument is made ready for deployment by setting the timing circuits to be initiated by bottom contact trigger and returning all the shuttters to an open position. It is presumed that descent through 2000 m of clear mid-water will wash down the machine sufficiently to clean it after previous deployments. Mid-water triggering could be accomplished by initiating the valve closures by a timer, knowing the descent rate to be

~45 m min^{-1}. It is then sent down by free-fall to the bottom where it collects water and runs through the sequence of valve closures ending with release of ballast and ascent to the surface.

Once on deck the BEAST is tilted and the eight compartments are vacuum filtered through 45 mm diameter, 0.4 μm pore size, Nuclepore® membrane filters. The membranes are mounted on in-line filter holders and connected to the BEASTs by a short length of tubing and to a 20 l carboy initially evacuated to 15—20 in. Hg of vacuum. The filtration of all the chambers is accomplished simultaneously to minimize differential pressures on the valves. In the 1983 trials the filters were weighted to 1 μg, stored in covered petri dishes, mounted on and removed from the filter holders in a glove box, and washed with 6 × 1 cc washes of distilled deionized water to remove salt. In a nepheloid layer of moderate concentration filter loadings are of the order of 200 μg. The procedures above which are very similar to those of Brewer et al. (1976) should give results good to ±5 μg for weighings and at most ±10 μg for weighing plus possible contamination errors.

ACKNOWLEDGEMENTS

The principle underlying the design of BEAST owes a great deal to discussions between I.N.M. and Dr. J.B. Southard who originally proposed a system and made a prototype employing shutters. We are grateful to Tina Coughanowr for her work on KN105 with the filtration system.

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APPENDIX 2

SEA TECH, INC.
P.O. Box 779 • Corvallis, Oregon 97339 • (503) 757-9716

June 18, 1984

Dr. Albert J. Williams 3rd
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Dear Sandy,

I have enclosed Optical Settling Tube interface instructions which should be helpfull in writing your data acquisition program to record data from the OST. If you have any questions regarding the operation of the OST please contact me. No more stories to tell about the return trip home.

Sincerely yours,

File Copy

Robert Bartz

OPTICAL SETTLING TUBE INTERFACE INFORMATION

1. The transmissometers are connected as outlined in the manual provided with the transmissometer.

2. The OST motor assembly is connected as follows:

Pin 1 - power on/off (motor off = 0 vdc, motor on = 5 vdc)
Pin 2 - micro switch (switch closes shorts pin 2 to ground thru 1 K)
Pin 3 - Signal ground
Pin 4 - Power ground (connect black lead from battery cable here)
Pin 5 - Power (Connect +15 VDC, yellow lead from battery cable here)

3. To synchronize the opening and closing of the OST lids, implement in software a program to test the time between closures of the micro switch. If the time is less than 90 seconds then the lids are closed. If the time is greater than 90 seconds then the lids are open. Lid closing time is 66 seconds and opening time is 396 seconds.

4. The prelaunch conditions should be set up to keep the lids open on the OST during lowering to the ocean bottom. The OST will implode if this is not done since the lids are water tight. The lids open will also allow the two transmissometers to be calibrated in the clean mid-water column. A suggested deployment procedure follows:

1) Just before launch open the OST lids 3/4 of the way by connecting a 5 VDC source from pin 3 (-), to pin 1 (+). Wash the OST and transmissometer windows with soapy water. At launch start a software timer.
2) After 2 hours turn motor power on (5 VDC to pin 1), turn motor power off when the micro switch closes, (pin 2 shorts to pin 3 thru 1 K). The lids will be completely open now.
3) After 2 hours turn motor power on to close the lids and again turn power off when the micro switch closes. The lids snap closed and then the motor runs for 30 seconds before the micro switch closes, this means that Time Zero is (micro switch closure minus 30 seconds). Start recording particle settling velocity data.
4) Open and close the lids as desired to obtain particle settling velocity data. The only restriction is that the lids should be left open for at least 15 minutes to collect a new sample.

The OST was set up as listed above last year to provide a 4 hour delay for lid closing to make sure the instrument was on the ocean bottom before closing the lids. Then a 22 hour lids close and 2 hour lids open cycle was programmed to obtain 1 sample a day. For a particle density of 1.5 gm/gm3 this 22 hour sample enabled us to evaluate particle sizes from 119 to 5.3 microns. For a particle density of 2 gm/gm3 the range was 84.1 to 3.7 microns.

5. Sample time can be programmed to obtain particle size data with one micron resolution from 4 to 100 microns, (particle density = 2) with a look-up table. Remember Time Zero is micro switch closure minus 30 seconds. The sample times to be programmed into the look-up table are listed in table 1 and 2. Table 1 is for particle density of 1.5 gm/gm3 and table 2 is for particle density of 2.0 gm/gm3. WHOI scientists should decide which table to use. To miminize problems with noisy data, each sample recorded should be the average of ten transmission values.

SETTLING TIME VS PARTICLE SIZE
PARTICLE DENSITY 2.0 GM/GM^3

DIAMETER	SETTLING TIME	SAMPLE TIME
100.00	84.6	84.5
99.00	86.3	86.5
98.00	88.1	88.0
97.00	89.9	90.0
96.00	91.8	92.0
95.00	93.8	94.0
94.00	95.8	96.0
93.00	97.8	98.0
92.00	100.0	100.0
91.00	102.2	102.0
90.00	104.5	104.5
89.00	106.8	107.0
88.00	109.3	109.5
87.00	111.8	112.0
86.00	114.4	114.5
85.00	117.1	117.0
84.00	119.9	120.0
83.00	122.8	123.0
82.00	125.8	126.0
81.00	129.0	129.0
80.00	132.2	132.0
79.00	135.6	135.5
78.00	139.1	139.0
77.00	142.7	142.5
76.00	146.5	146.5
75.00	150.4	150.5
74.00	154.5	154.5
73.00	158.8	159.0
72.00	163.2	163.0
71.00	167.8	168.0
70.00	172.7	172.5
69.00	177.7	177.5
68.00	183.0	183.0
67.00	188.5	188.5
66.00	194.2	194.0
65.00	200.3	200.5
64.00	206.6	206.5
63.00	213.2	213.0
62.00	220.1	220.0
61.00	227.4	227.5
60.00	235.0	235.0
59.00	243.1	243.0
58.00	251.5	251.5
57.00	260.4	260.5
56.00	269.8	270.0
55.00	279.7	279.5
54.00	290.2	290.0
53.00	301.2	301.0
52.00	312.9	313.0
51.00	325.3	325.5

TABLE 1

SETTLING TIME VS PARTICLE SIZE
PARTICLE DENSITY 2.0 GM/GM^3

DIAMETER	SETTLING TIME	SAMPLE TIME
50.00	338.4	338.5
49.00	352.4	352.5
48.00	367.2	367.0
47.00	383.0	383.0
46.00	399.9	400.0
45.00	417.8	418.0
44.00	437.0	437.0
43.00	457.6	457.5
42.00	479.6	479.5
41.00	503.3	503.5
40.00	528.8	529.0
39.00	556.3	556.5
38.00	585.9	586.0
37.00	618.0	618.0
36.00	652.9	653.0
35.00	690.7	690.5
34.00	731.9	732.0
33.00	777.0	777.0
32.00	826.3	826.5
31.00	880.4	880.5
30.00	940.1	940.0
29.00	1006.1	1006.0
28.00	1079.2	1079.0
27.00	1160.6	1160.5
26.00	1251.6	1251.5
25.00	1353.8	1354.0
24.00	1468.9	1469.0
23.00	1599.4	1599.5
22.00	1748.1	1748.0
21.00	1918.6	1918.5
20.00	2115.3	2115.5
19.00	2343.8	2344.0
18.00	2611.4	2611.5
17.00	2927.7	2927.5
16.00	3305.1	3305.0
15.00	3760.5	3760.5
14.00	4316.8	4317.0
13.00	5006.5	5006.5
12.00	5875.7	5875.5
11.00	6992.6	6992.5
10.00	8461.0	8461.0
9.00	10445.7	10445.5
8.00	13220.3	13220.5
7.00	17267.4	17267.5
6.00	23502.8	23503.0
5.00	33844.1	33844.0
4.00	52881.4	52881.5
3.00	94011.4	94011.5
2.00	211525.6	211525.5
1.00	846102.3	846102.5

TABLE 1

SETTLING TIME VS PARTICLE SIZE
PARTICLE DENSITY 1.5 GM/GM^3

DIAMETER	SETTLING TIME	SAMPLE TIME
100.00	178.7	178.5
99.00	182.3	182.5
98.00	186.0	186.0
97.00	189.9	190.0
96.00	193.8	194.0
95.00	198.0	198.0
94.00	202.2	202.0
93.00	206.6	206.5
92.00	211.1	211.0
91.00	215.7	215.5
90.00	220.6	220.5
89.00	225.5	225.5
88.00	230.7	230.5
87.00	236.0	236.0
86.00	241.6	241.5
85.00	247.3	247.5
84.00	253.2	253.0
83.00	259.3	259.5
82.00	265.7	265.5
81.00	272.3	272.5
80.00	279.1	279.0
79.00	286.3	286.5
78.00	293.6	293.5
77.00	301.3	301.5
76.00	309.3	309.5
75.00	317.6	317.5
74.00	326.2	326.0
73.00	335.2	335.0
72.00	344.6	344.5
71.00	354.4	354.5
70.00	364.6	364.5
69.00	375.2	375.0
68.00	386.4	386.5
67.00	398.0	398.0
66.00	410.1	410.0
65.00	422.8	423.0
64.00	436.2	436.0
63.00	450.1	450.0
62.00	464.8	465.0
61.00	480.1	480.0
60.00	496.3	496.5
59.00	513.2	513.0
58.00	531.1	531.0
57.00	549.9	550.0
56.00	569.7	569.5
55.00	590.6	590.5
54.00	612.7	612.5
53.00	636.0	636.0
52.00	660.7	660.5
51.00	686.9	687.0

TABLE 2

SETTLING TIME VS PARTICLE SIZE
PARTICLE DENSITY 1.5 GM/GM^3

DIAMETER	SETTLING TIME	SAMPLE TIME
50.00	714.6	714.5
49.00	744.1	744.0
48.00	775.4	775.5
47.00	808.7	808.5
46.00	844.3	844.5
45.00	882.2	882.0
44.00	922.8	923.0
43.00	966.2	966.0
42.00	1012.8	1013.0
41.00	1062.8	1063.0
40.00	1116.6	1116.5
39.00	1174.6	1174.5
38.00	1237.2	1237.0
37.00	1305.0	1305.0
36.00	1378.5	1378.5
35.00	1458.4	1458.5
34.00	1545.4	1545.5
33.00	1640.5	1640.5
32.00	1744.6	1744.5
31.00	1859.0	1859.0
30.00	1985.0	1985.0
29.00	2124.3	2124.5
28.00	2278.7	2278.5
27.00	2450.6	2450.5
26.00	2642.8	2643.0
25.00	2858.4	2858.5
24.00	3101.6	3101.5
23.00	3377.1	3377.0
22.00	3691.1	3691.0
21.00	4051.0	4051.0
20.00	4466.3	4466.5
19.00	4948.8	4949.0
18.00	5513.9	5514.0
17.00	6181.7	6181.5
16.00	6978.5	6978.5
15.00	7940.0	7940.0
14.00	9114.8	9115.0
13.00	10571.1	10571.0
12.00	12406.3	12406.5
11.00	14764.5	14764.5
10.00	17865.1	17865.0
9.00	22055.7	22055.5
8.00	27914.2	27914.0
7.00	36459.4	36459.5
6.00	49625.2	49625.0
5.00	71460.3	71460.5
4.00	111656.8	111657.0
3.00	198501.0	198501.0
2.00	446627.2	446627.0
1.00	1786508.6	1786508.5

TABLE 2

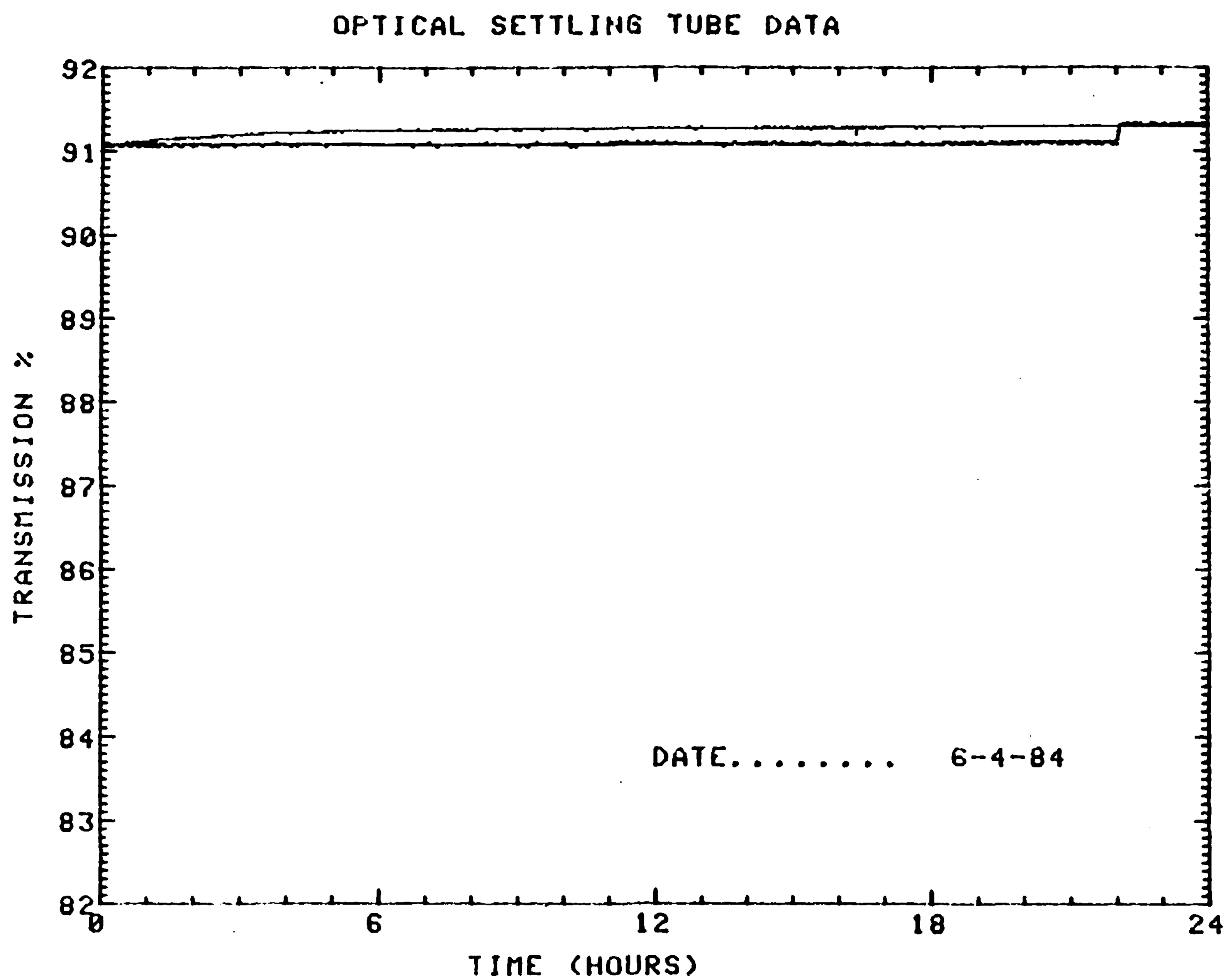
OPTICAL SETTLING TUBE DATA

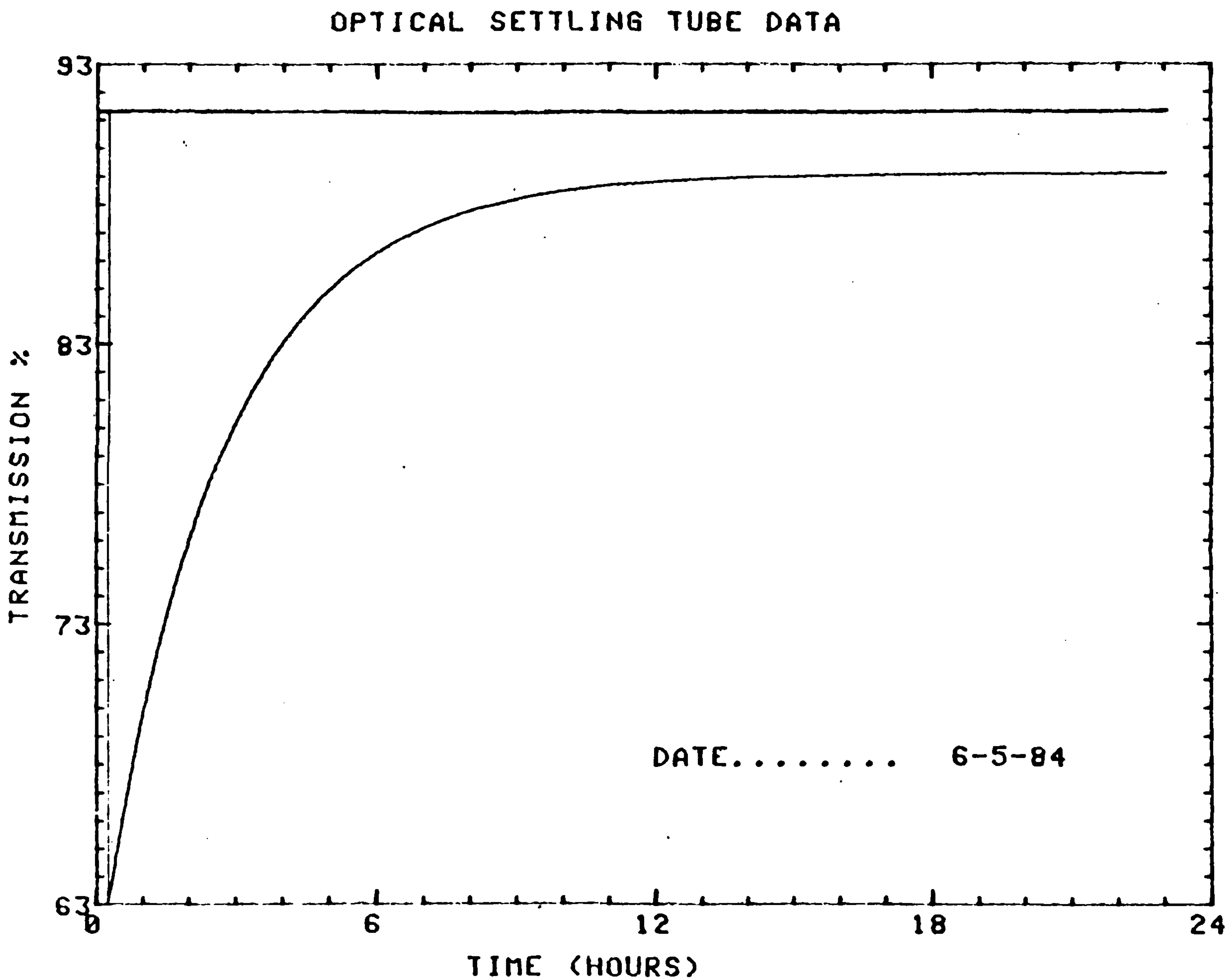
The tests to determine the performance of the OST were conducted in a large fresh water tank. A pump was used to circulate water around the settling tube at approximately 5 cm/sec. The water was filtered continuously to simulate a variable particle suspension environment for the following tests.

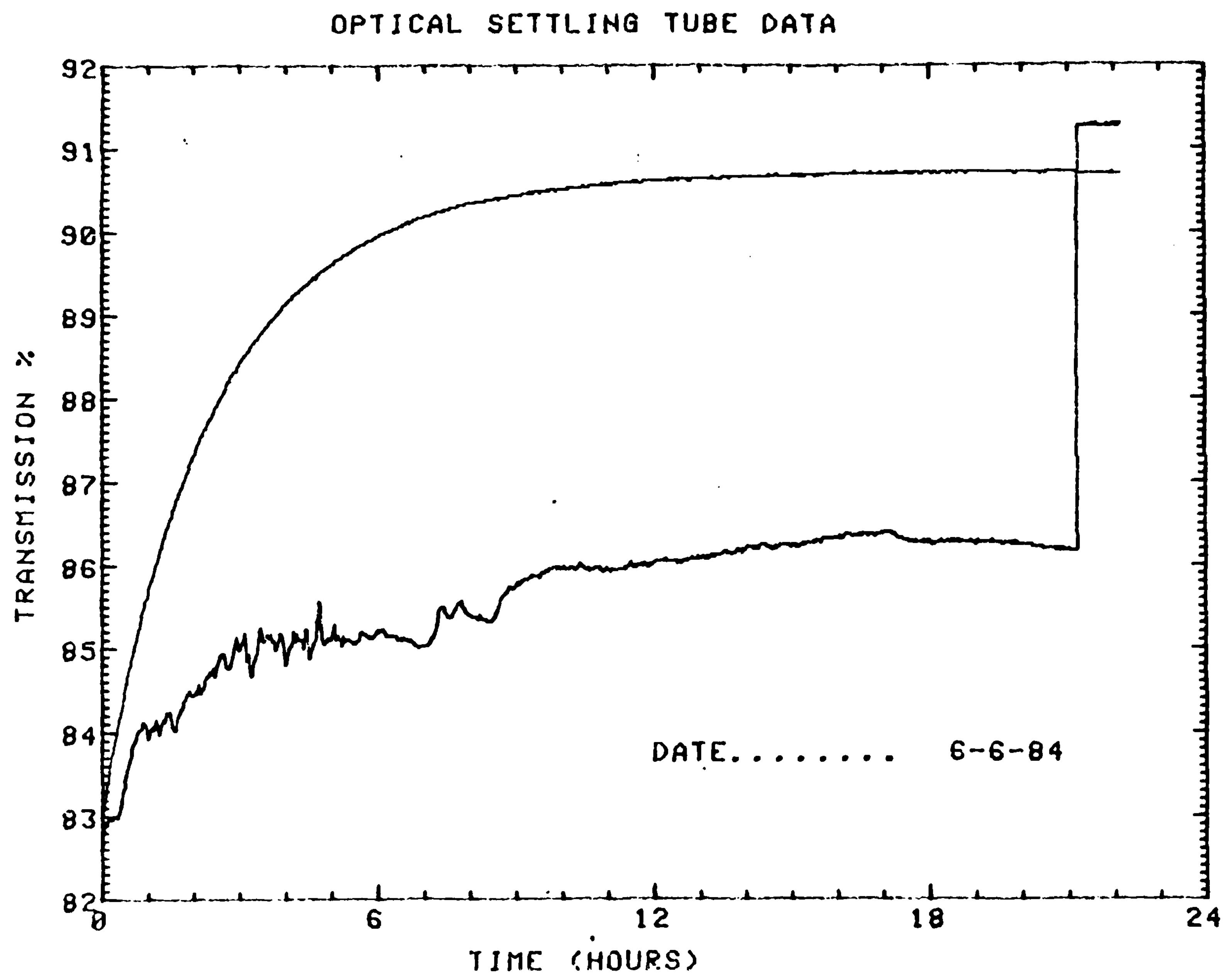
Figure 1 shows data for clean water inside and outside the OST, which demonstrates the stability of the OST.

Figure 2 demonstrates that the lids seal adequately. The lids were closed with clean water inside the OST and then HEBBLE mud was added to the tank to lower the transmission to 63%.

Figure 3 shows the particle settling data for HEBBLE mud. The mud was added to the tank and then the pump and filter were turned on at high speed to mix the mud thoroughly. When the transmission in the tank reached 83% the OST lids were closed.


OPTICAL SETTLING TUBE DATA
TRANSMISSION %
92
91
90
89
88
87
86
85
84
83
82
0
6
12
18
24
TIME (HOURS)
DATE........ 6-4-84


OPTICAL SETTLING TUBE DATA
93
83
73
63
TRANSMISSION %
0
6
12
18
24
TIME (HOURS)
DATE........ 6-5-84


OPTICAL SETTLING TUBE DATA
TRANSMISSION %
92
91
90
89
88
87
86
85
84
83
82
0
6
12
18
24
TIME (HOURS)
DATE........ 6-6-84

APPENDIX 3

Woods Hole Oceanographic Institution
Woods Hole, MA 02543
August 29, 1984

Bob Bartz, President
Sea Tech, Inc.
Box 779
Corvallis, OR 97339

Dear Bob,

We almost got the optical settling tube working but we ran out of time. Chris Converse, Dunn's replacement, reinstalled the bellows you sent us, topped it up with Bray oil, and bled out the trapped air. The ROST was mounted toward the end of July to the underside of the grating on the GLASS Tripod. Aluminum brackets were welded up to provide a stiff mount. The transmissometers were about 2 meters high. Nothing further was done mechanically to the system until we went to sea August 18.

The work on BASS became intense, involving hardware debugging of noise on the A/D and program generation. The night before sailing, no programs suitable for the long deployment had yet been written although the work had been going nearly around the clock for two weeks. The BASS instruments had been buttoned up with an event triggered program in them that would record an hour of raw data to the Event Recorder, a minimum requirement so that we could do bucket velocity zeros and dock level tapes before we sailed. This recorder can hold only four hours of data or four triggered events. Bayshore 2 BASS, the one connected to ROST measured the transmission from four transmissometers, the two on ROST and two others on the GLASS tripod. However it would do so only four times in the long deployment.

An algorithm had been developed to process data for 20 minutes and write a record of mean quantities to a second tape at the end of that time. Each day 72 of these records would be written. There was space in that record for 14 samples of ROST data or 1008 samples per day. I had a plan to sample ROST fast initially, then less frequently in a roughly logarithmic sequence over 9 sample rates. The samples were to have been stacked in memory as taken and slowly stripped out and written to tape as the 20 minute average blocks were written.

At sea, Tom Gross and I continued to work on the BASS processing algorithm. The algorith was about 700 lines long and had to be debugged. In essence it took the mean of the cross products of velocity from the BASS sensors after subtracting the product of the means. The hard part was that the numbers were 48 bits long and my hardware multiply/divide unit was only two bytes

wide, handling 32 bit divisions. Remainders had to be kept and multiplied by things and added back in in a four pass procedure. The debugging was hampered by our inability to get BASS to work with a logic analyzer or micromonitor connected. Only results could be checked. For the first round of deployments the velocity means were processed but the cross product means were bypassed.

Meanwhile I worked on a command detecting algorithm to recognize event commands received by my Acoustic Command Receivers. The rule was that an event would not be acknowledged unless two of four transmitted commands were received 106 seconds apart. This was accomplished and tested on the first round of deployments by sending commands from the surface.

Next I implemented a door opening and closing algorithm for ROST. It was noticed that the rubber tubing was flattened and cracked on the door opening mechanism but you had provided replacement materials so this was replaced. I suspect that the sun was permitted to degrade the tubing while ROST sat on the GLASS tripod before the cruise. Chris Dunn broke his shoulder and was out of work for some time while Chris Converse mounted ROST and perhaps the message about protecting the rubber from sunlight didn't get transmitted. I don't remember foil on the ROST while it sat on the lawn. In any case, it was replaced and run through a few cycles and worked well after its first deployment. I only used the door algorithm for the second deployment. For recording ROST's transmissometers, I depended on the 5 minute samples of all auxillary sensors including ROST's for the 20 minute block records.

The door algorithm called for opening at midnight and closing at 0200. Because we wanted the door open on descent, I set the clock to Central Standard Time which gave midnight at our launch time. The door was partly open at launch. However on recovery, the door was open although it was four hours before opening time. While we tied the tripod down, the doors slammed shut. We could not be certain that the clock had not reset itself when BASS was turned on so I thought that it was possible that it had just chosen this time to close by chance.

Finally I completed the event detecting algorithm for Master BASS with the command transmitting routine. This was loaded in the instrument about 4PM and a test started of the event detection by putting a filter in the transmissometer path. Then I turned my attention to the loading of fast ROST data for storing in the 20 minute blocks of GLASS. This was finished about 2AM and loaded into BASS. The launch occured as soon as things were buttoned up and we were on station. By 6AM we were headed home.

A summary of the problem is reproduced below from my failure report:

GLASS

The third deployment of GLASS for the long duration is marred by the failure of ROST. BASS was to have controlled ROST by opening and closing its doors and powering and recording its transmissometers. On the first deployment of GLASS, no attempt was made to control ROST. It was deployed with its doors partly open and its transmissometers were recorded along with the rest. On the second deployment, the doors were controlled by BASS and scheduled to open at midnight and close at 0200. When recovered, the doors were still moving and the event recorder was full.

Two mistakes caused this result. The microswitch sensing line had been double inverted when single inversion was required. Thus the sense of closure of the microswitch was inverted and the motor ran when it should have stopped. Second, the event flag line used by the microswitch was shared by the Command Receiver. This caused a closed microswitch to be interpreted by the Command Detector as an Event Command which filled the Event Tape quickly.

The first error was fixed on the circuit board by taking the output from the first inverter instead of the second. The second was corrected by tying the sense resistor of the microswitch to the motor controller line so that it could be switched off for command testing and disabled when the motor was not running. A software fix was provided to turn off the motor, deselecting the microswitch, when testing the command flag.

For the third deployment of GLASS, the data sequence was enhanced to sample ROST transmissometers every 10 seconds starting at door closing time and lasting 48 minutes and trickle this data back, four samples at a time, on the 20 minute average blocks for the next 24 hours. Meanwhile the five minute samples of all transmissometers would be recorded. This would have given fast data for the first part of the experiment and five minute data throughout.

At launch, the doors were partly opened to prevent implosion and to calibrate the transmissometer in the midwater. The time was about 0800 GMT so no motor action was expected. However when turned on the BASS started to open ROST's doors. Launch was delayed and soon BASS started to close ROST's doors and then they did close. Next the launch sequence started and it appeared that ROST would go down with its doors closed which was dangerous. So I cut the elastic door closers permitting the bottom door to open and so it was launched.

It is not clear whether the fault that caused the motor to run was hardware or software. Neither was adequately debugged for lack of time. From schematics and program listings there should have been no problem so it remains a mystery.

Yours truly,

Sandy Williams

Sandy Williams

APPENDIX 4

July 30, 1985

Dr. A.J. Williams III
Woods Hole Oceanographic Inst.
Woods Hole, MA 02543

Dear Sandy,

The ROST transmissometer has been recalibrated. Its new values are listed on the bottom of the operating instructions for S.N. 58D. The water calibration was rechecked for S.N. 42D and it did not change even though the air calibration did. Clean water gives a value of 4.558 with a zero of +0.003. I am also including a copy of the original calibration of S.N. 42D in case you may have lost it.

The connectors for the motor have changed. They are as follows:

Pin 1	Micro switch
Pin 2	Motor on
Pin 3	Ground
Pin 4	Ground
Pin 5	+ 12VDC

I did not change the batteries in the battery pack, put new ones in before launch.

Sincerely Yours,

Robert Bartz
President

25 CM TRANSMISSOMETER OPERATING INSTRUCTIONS

OPERATION & CALIBRATION:

First connect a power source (8 to 15 VDC) to the instrument as shown on the connector wiring diagram, (+) to pin 4 and (-) to pin 1.

Use a voltmeter to measure the output voltage, (+) to pin 2 and (-) to pin 3.

Block the light path to measure the zero output, it should be 0.00 +/- .01 VDC.

Clean the windows, using kimwipes (soft paper—nonabrasive), with a solution of dishwashing liquid and water. This should remove any material from the windows. When the windows are clean, the output voltage in air should be within +/- .02 VDC of the AIR CALIBRATION value listed below.

Perform the above procedure before each calibration and use of the instrument to measure transmission of water. The wavelength of the light source is 660 nm and at this wavelength the maximum value for light transmission in clean water with a 25 cm pathlength is 91.3 % (4.565 VDC)

MOUNTING INSTRUCTIONS:

A mounting bracket is provided with the transmissometer to simplify mounting the instrument on your system.

PRECAUTIONS:

DO NOT OPEN THE INSTRUMENT—this voids the warranty. If the instrument does not function properly, please consult the factory.

DO NOT LEAVE THE INSTRUMENT ON WHEN NOT IN USE. The LED is quite stable; but will decrease in intensity, like most light sources, if left on for a long period of time.

DATA REDUCTION:

Air calibration may change with time. The LED light output can decrease approximately 1 % in 1000 hours of operation. If the air calibration is measured frequently and the following correction is applied, then this change can be compensated for and will not effect the accuracy of the data.

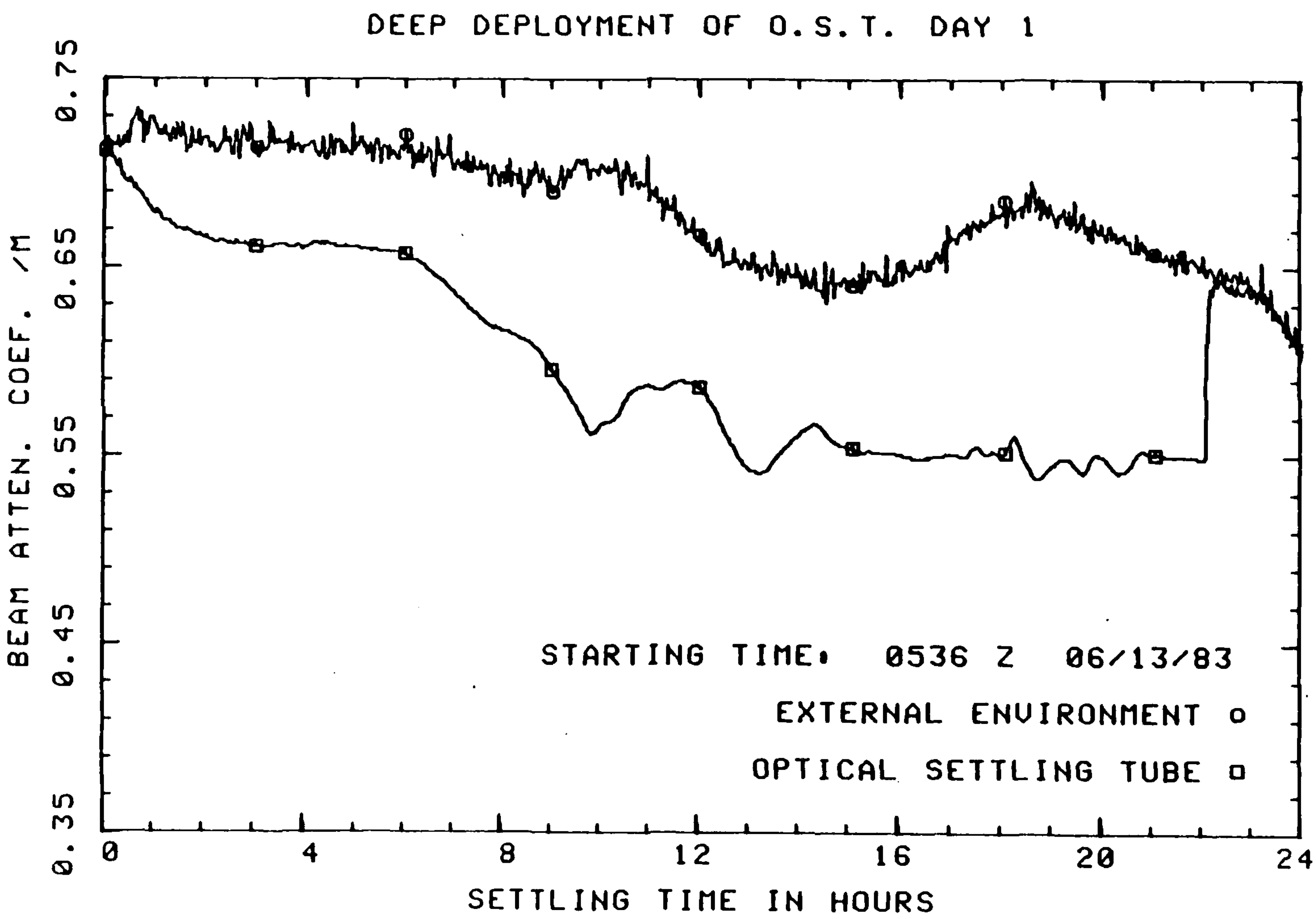
$$V=(A/B)*(X-Z)$$

- V = Corrected output voltage, (5 VDC corresponds to 100 % Transmission in water)
- A = Air calibration value listed below
- B = Air calibration (present value)
- X = Data value (output voltage measured in water)
- Z = Zero offset with the light path blocked

The AIR CALIBRATION for S.N. 58D was 4.759 VDC on 07/29/85

The ZERO OFFSET with light path blocked is 0.000 VDC

APPENDIX 5


DEEP DEPLOYMENT OF O.S.T. DAY 1
0.75
0.65
0.55
0.45
0.35
BEAM ATTEN. COEF. /M
0
4
8
12
16
20
24
SETTLING TIME IN HOURS
STARTING TIME: 0536 Z 06/13/83
EXTERNAL ENVIRONMENT o
OPTICAL SETTLING TUBE □

HEBBLE OST DATA
DATE 06/13/83

RECORD	D,AV	D,1	D,2	B.A.C	C1-C2	NP	SV
0004	84.1	89.1	79.4	0.7147	-0.0002	0000.0	0.21062
0005	74.9	79.4	70.7	0.7149	-0.0001	0000.0	0.16717
0006	66.8	70.7	63.0	0.7151	0.0000	0000.0	0.13268
0007	59.5	63.0	56.1	0.7151	0.0003	0000.0	0.10531
0009	53.0	56.1	50.0	0.7148	0.0007	0000.2	0.08359
0012	47.2	50.0	44.6	0.7140	0.0016	0000.5	0.06634
0015	42.1	44.6	39.7	0.7124	0.0031	0001.1	0.05266
0024	33.4	39.7	31.2	0.7094	0.0039	0002.2	0.03255
0029	30.1	31.2	28.0	0.7054	0.0007	0000.5	0.02694
0037	26.6	28.0	24.9	0.7048	0.0057	0005.0	0.02111
0047	23.6	24.9	22.2	0.6990	0.0027	0003.0	0.01662
0059	21.1	22.2	19.8	0.6963	0.0021	0003.0	0.01324
0074	18.8	19.8	17.6	0.6942	0.0059	0010.2	0.01056
0094	16.7	17.6	15.7	0.6882	0.0064	0014.0	0.00831
0118	14.9	15.7	14.0	0.6818	0.0050	0014.8	0.00662
0149	13.3	14.0	12.5	0.6768	0.0056	0020.6	0.00524
0188	11.8	12.5	11.1	0.6712	0.0042	0018.3	0.00416
0237	10.5	11.1	9.9	0.6670	0.0035	0021.7	0.00330
0299	9.4	9.9	8.8	0.6635	0.0022	0014.8	0.00261
0376	8.4	8.8	7.9	0.6613	-0.0003	0000.0	0.00208
0474	7.4	7.9	7.0	0.6616	0.0003	0003.3	0.00165
0598	6.6	7.0	6.2	0.6613	0.0063	0082.0	0.00131
0753	5.9	6.2	5.6	0.6549	0.0296	0572.3	0.00104
0949	5.3	5.6	4.9	0.6253	0.0420	1090.3	0.00082
1196	4.7	4.9	4.4	0.5833	0.0110	0292.0	0.00065
1507	4.2	4.4	3.9	0.5723	0.0178	0542.0	0.00052
1899	3.7	3.9	3.5	0.5545	0.0058	0251.0	0.00041

CONCENTRATION-WEIGHTED SETTLING VELOCITY = 0.01740 CM/SEC

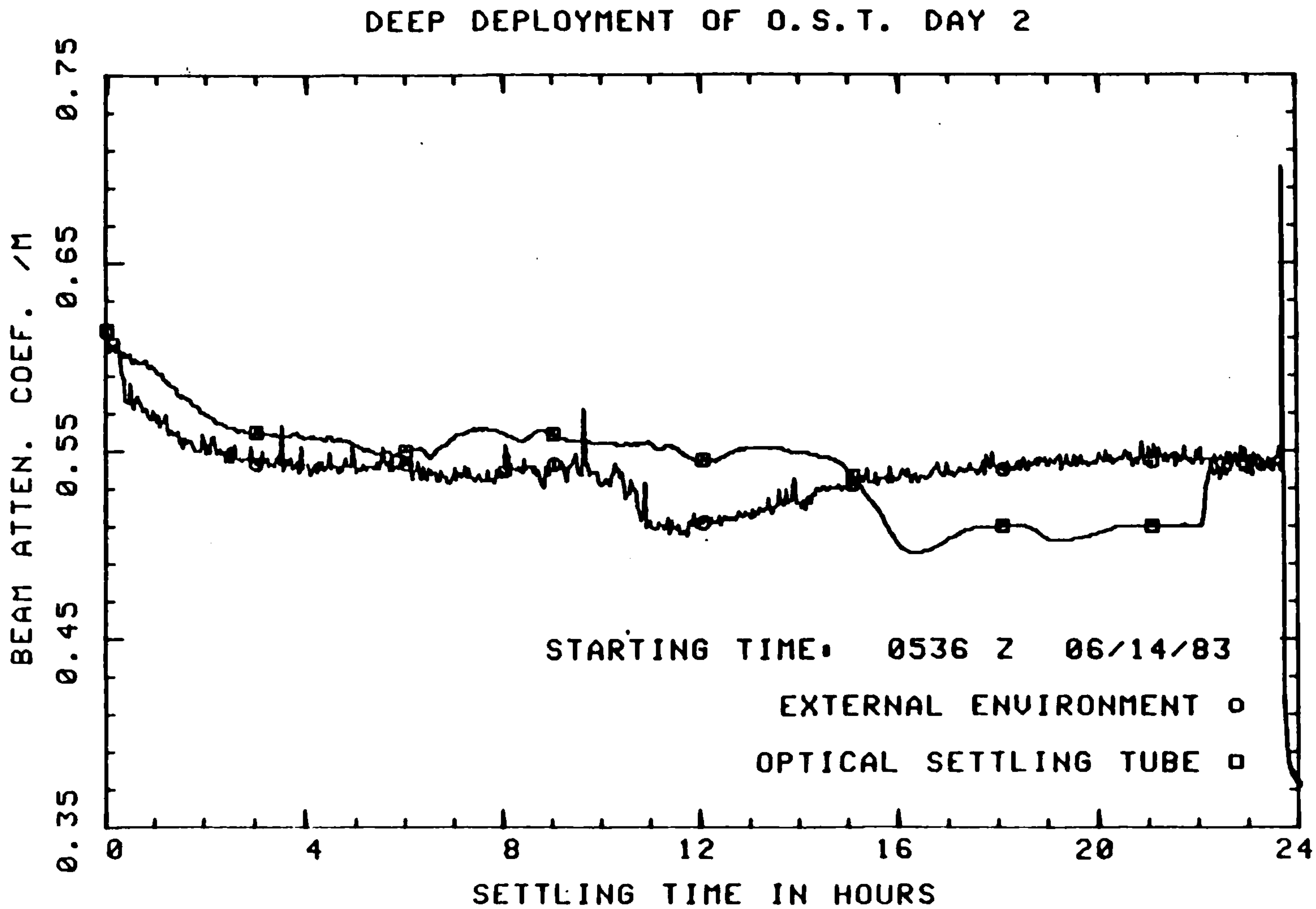
Density = 2

HEBBLE OST DATA
DATE 06/13/83

RECORD	D,AV	D,1	D,2	B.A.C	C1-C2	NP	SV
0004	119.0	126.0	112.3	0.7148	-0.0002	0000.0	0.19950
0005	106.0	112.3	100.0	0.7150	-0.0001	0000.0	0.15835
0006	94.4	100.0	89.1	0.7151	0.0000	0000.0	0.12568
0008	84.1	89.1	79.4	0.7150	0.0004	0000.0	0.09975
0010	74.9	79.4	70.7	0.7147	0.0009	0000.1	0.07917
0012	66.8	70.7	63.0	0.7138	0.0019	0000.3	0.06284
0016	59.5	63.0	56.1	0.7119	0.0035	0000.6	0.04988
0025	47.2	56.1	44.1	0.7083	0.0031	0000.9	0.03125
0031	42.3	44.1	39.5	0.7053	0.0020	0000.7	0.02520
0039	37.7	39.5	35.3	0.7033	0.0050	0002.3	0.02003
0049	33.6	35.3	31.5	0.6983	0.0018	0001.0	0.01594
0062	29.9	31.5	28.0	0.6966	0.0041	0003.0	0.01260
0078	26.7	28.0	25.0	0.6924	0.0054	0004.7	0.01002
0099	23.7	25.0	22.2	0.6870	0.0061	0006.7	0.00789
0125	21.1	22.2	19.8	0.6810	0.0057	0008.0	0.00625
0157	18.8	19.8	17.6	0.6752	0.0049	0008.6	0.00498
0198	16.7	17.6	15.7	0.6703	0.0046	0010.0	0.00395
0250	14.9	15.7	14.0	0.6657	0.0026	0007.7	0.00313
0315	13.3	14.0	12.5	0.6631	0.0018	0006.9	0.00248
0397	11.8	12.5	11.1	0.6613	-0.0006	0000.0	0.00197
0501	10.5	11.1	9.9	0.6618	0.0014	0008.8	0.00156
0631	9.4	9.9	8.8	0.6604	0.0101	0067.8	0.00124
0795	8.3	8.8	7.9	0.6503	0.0324	0309.7	0.00098
1002	7.4	7.9	7.0	0.6179	0.0388	0456.2	0.00078
1263	6.6	7.0	6.2	0.5791	0.0138	0178.6	0.00062
1591	5.9	6.2	5.6	0.5653	0.0118	0227.6	0.00049
2004	5.3	5.6	4.9	0.5536	-0.0029	0000.0	0.00039

CONCENTRATION-WEIGHTED SETTLING VELOCITY = 0.01252 CM/SEC

Density = 1.5


DEEP DEPLOYMENT OF O.S.T. DAY 2
0.75
0.65
0.55
0.45
0.35
BEAM ATTEN. COEF. /M
0
4
8
12
16
20
24
SETTLING TIME IN HOURS
STARTING TIME: 0536 Z 06/14/83
EXTERNAL ENVIRONMENT o
OPTICAL SETTLING TUBE □

HEBBLE OST DATA
DATE 06/14/83

RECORD	D,AV	D,1	D,2	B.A.C	C1-C2	NP	SV
0004	84.1	89.1	79.4	0.6065	0.0001	0000.0	0.21662
0005	74.9	79.4	70.7	0.6064	0.0001	0000.0	0.15717
0006	66.8	70.7	63.0	0.6063	0.0001	0000.0	0.13268
0007	59.5	63.0	56.1	0.6062	0.0002	0000.0	0.10531
0009	53.0	56.1	50.0	0.6060	0.0002	0000.1	0.08359
0012	47.2	50.0	44.6	0.6058	0.0003	0000.1	0.06634
0015	42.1	44.6	39.7	0.6055	0.0004	0000.2	0.05265
0024	33.4	39.7	31.2	0.6051	0.0012	0000.7	0.03255
0029	30.1	31.2	28.0	0.6039	0.0014	0001.0	0.02694
0037	26.6	28.0	24.9	0.6024	0.0011	0001.0	0.02111
0047	23.6	24.9	22.2	0.6013	0.0015	0001.7	0.01662
0059	21.1	22.2	19.8	0.5998	0.0018	0002.5	0.01324
0074	18.8	19.8	17.6	0.5980	0.0005	0000.9	0.01056
0094	16.7	17.6	15.7	0.5975	0.0025	0005.4	0.00831
0118	14.9	15.7	14.0	0.5951	0.0067	0019.6	0.00662
0149	13.3	14.0	12.5	0.5884	0.0080	0029.7	0.00524
0188	11.8	12.5	11.1	0.5804	0.0081	0034.7	0.00416
0237	10.5	11.1	9.9	0.5723	0.0082	0050.7	0.00330
0299	9.4	9.9	8.8	0.5641	0.0042	0028.0	0.00261
0376	8.4	8.8	7.9	0.5599	0.0019	0017.6	0.00208
0474	7.4	7.9	7.0	0.5581	0.0034	0040.1	0.00165
0598	6.6	7.0	6.2	0.5547	0.0051	0065.9	0.00131
0753	5.9	6.2	5.6	0.5496	-0.0093	0000.0	0.00104
0949	5.3	5.6	4.9	0.5589	0.0025	0065.2	0.00082
1196	4.7	4.9	4.4	0.5564	0.0066	0175.5	0.00065
1507	4.2	4.4	3.9	0.5498	0.0233	0710.2	0.00052
1899	3.7	3.9	3.5	0.5264	0.0190	0822.1	0.00041

CONCENTRATION-WEIGHTED SETTLING VELOCITY = 0.01100 CM/SEC

Density = 2

HEBBLE OST DATA
DATE 06/14/83

RECORD	D.AV	D.1	D.2	B.A.C	C1-C2	NP	SV
0004	119.0	126.0	112.3	0.6065	0.0001	0000.0	0.19950
0005	106.2	112.3	100.0	0.6064	0.0001	0000.0	0.15835
0006	94.4	100.0	89.1	0.6063	0.0001	0000.0	0.12568
0008	84.1	89.1	79.4	0.6061	0.0002	0000.0	0.09975
0010	74.9	79.4	70.7	0.6060	0.0002	0000.0	0.07917
0012	66.8	70.7	63.0	0.6057	0.0003	0000.0	0.06284
0016	59.5	63.0	56.1	0.6054	0.0005	0000.1	0.04988
0025	47.2	56.1	44.1	0.6049	0.0014	0000.4	0.03125
0031	42.3	44.1	39.5	0.6035	0.0013	0000.5	0.02520
0039	37.7	39.5	35.3	0.6021	0.0010	0000.5	0.02003
0049	33.6	35.3	31.5	0.6011	0.0019	0001.1	0.01594
0062	29.9	31.5	28.0	0.5992	0.0011	0000.8	0.01260
0078	26.7	28.0	25.0	0.5980	0.0008	0000.7	0.01002
0099	23.7	25.0	22.2	0.5972	0.0035	0003.8	0.00789
0125	21.1	22.2	19.8	0.5937	0.0070	0009.8	0.00625
0157	18.8	19.8	17.6	0.5868	0.0081	0014.2	0.00498
0198	16.7	17.6	15.7	0.5786	0.0083	0018.1	0.00395
0250	14.9	15.7	14.0	0.5703	0.0076	0022.4	0.00313
0315	13.3	14.0	12.5	0.5627	0.0035	0012.9	0.00248
0397	11.8	12.5	11.1	0.5592	0.0016	0007.0	0.00197
0501	10.5	11.1	9.9	0.5576	0.0047	0029.2	0.00156
0631	9.4	9.9	8.8	0.5529	0.0017	0011.8	0.00124
0795	8.3	8.8	7.9	0.5511	-0.0007	0000.0	0.00098
1002	7.4	7.9	7.0	0.5598	0.0049	0057.3	0.00078
1263	6.6	7.0	6.2	0.5549	0.0059	0076.4	0.00062
1591	5.9	6.2	5.6	0.5490	0.0322	0624.3	0.00049
2004	5.3	5.6	4.9	0.5168	0.0061	0158.3	0.00039

CONCENTRATION-WEIGHTED SETTLING VELOCITY = 0.00082 CM/SEC

Density = 1.5

END
FILMED
4-86
DTIC